

prising photo absorption characteristics and range similar to those of the first barrier layer 34, may include a different material from those of the first barrier layer 34, some combination thereof, etc. When the second barrier layer 38 is a doped layer, the second barrier layer 38 may be differently doped relative to the first barrier layer 34. For example, one of the first and second barriers 34 and 38 may be doped with a p-type dopant and the other of the first and second barriers 34 and 38 may be doped with an n-type dopant. A portion of the second barrier layer 38 may be in contact with the first barrier layer 34. A portion of the upper side surface of the horizontal channel unit 36<sub>m</sub> of the second channel layer 36 may be exposed after the second barrier layer 38 is formed, as shown in FIG. 13(b). In some embodiments, when another barrier layer is not further formed on the second barrier layer 38, the second barrier layer 38 may be formed to cover a complete portion of the upper side surface of the horizontal channel unit 36<sub>m</sub>.

[0114] Referring to FIG. 14(a) and FIG. 14(b), a third channel layer 80 is formed to cover the upper side surface of the second barrier layer 38. The third channel layer 80 is formed to be in contact with the first channel layer 32. The third channel layer 80 may also be formed of a 2D material layer or a semiconductor layer in a single layer. The third channel layer 80 is formed to cover left side surfaces of the first and second barrier layers 34 and 38. A portion of the third channel layer 80 covering the upper side surface of the second barrier layer 38 may correspond to the top channel layer 32<sub>t</sub> of FIG. 3. A portion of the third channel layer 80 covering side surfaces of the first and second barrier layers 34 and 38 may correspond to the side channel layer 32<sub>s</sub> of FIG. 3. After the third channel layer 80 is formed, the drain electrode 42D may be formed on the first channel layer 32 and the source electrode 42S may be formed on the second channel layer 36. The source and the drain electrodes 42S and 42D may be also formed before the third channel layer 80 is formed.

[0115] In the optical devices illustrated in FIGS. 6 and 8, more than two barrier layers are repeatedly laminated over the insulating layer 30, and channel layers different from one another are alternately laminated between barrier layers. Thus, the optical devices illustrated in FIGS. 5-6, 8, and 9-10 may be also formed, without difficulty, based on the method presented in FIGS. 11 through 14.

[0116] An overall thickness of barrier layers, photo absorption layers, including the 2D material of the optical devices according to the exemplary embodiments may have a sufficient thickness to configure the barrier layers to absorb all of incident light. Here, the "sufficient thickness" may include a minimum thickness to absorb all of incident light, or either thicker or thinner than the minimum thickness. Accordingly, a photo absorption rate of the optical devices according to the exemplary embodiments may be equal to or more than that of conventional optical devices. In addition, a photo absorption layer including the 2D material in the optical devices according to the exemplary embodiments may be divided into a plurality of layers, while a thickness of each divided layer is thin and may be controlled to be the thickness to maximize the photo separation efficiency during a manufacturing process. Thus, when light is incident on the photo absorption layer, electrons and holes accordingly generated may move from the photo absorption layer out to electrodes or channel layers adjacent to the photo absorption layer. By using the optical devices according to the exem-

plary embodiments both photo absorption rate and photo separation efficiency may be increased.

[0117] In addition, since the photo absorption layer of the optical devices according to the exemplary embodiments may be a layer including the 2D material, and electrodes existing between a plurality of layers included in the photo absorption layer are the 2D material, such as graphene, electrodes, the optical devices presented in the exemplary embodiments may be realized in a thin membrane shape with a large area and applied to flexible devices.

[0118] In addition, the optical devices according to some embodiments may be applied to an optical apparatus or a photo electronic apparatus, using photo absorption, and electrons and holes accordingly generated, such as a CMOS charge image sensor, a photodetector of a health monitoring device, a solar cell, etc.

[0119] The foregoing description has been provided for purposes of illustration and description. It is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular example embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of the disclosure.

[0120] While some embodiments have been described with reference to the figures, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the optical devices according to the exemplary embodiments as defined by the following claims. Thus, the true technological protection range of the present inventive concepts should be defined by the patent claims below.

1. An optical device comprising:
  - a bottom channel layer on a substrate;
  - a barrier stack on the bottom channel layer, the barrier stack including at least two barrier layers at least partially interposed by a channel unit;
  - a top channel layer on the barrier stack;
  - a drain electrode connected to the bottom channel layer and the top channel layer; and
  - a source electrode connected to the channel unit.
2. The optical device of claim 1, wherein the barrier stack further includes one or more barrier layers at least partially interposed by separate channel layers connected to either the drain electrode or to the source electrode in an alternating interposing sequence.
3. The optical device of claim 1, wherein at least one barrier layer of the at least two barrier layers includes at least one of a two-dimensional (2D) material layer or a semiconductor layer.
4. The optical device of claim 1, wherein the bottom channel layer includes a metal layer.
5. The optical device of claim 1, wherein the bottom channel layer and the top channel layer are doped in a first doping type, and the channel unit is doped in a second doping type which is opposite to the first doping type.
6. The optical device of claim 1, wherein a thickness of each barrier layer of the first barrier layer and the second barrier layer is less than a particular distance traveled by